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Volume Equations for New Mexico's Pinyon-Juniper Dryland Forests

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RESEARCH SUMMARY

New equations were developed to predict wood volume for New Mexico's *Pinus edulis*, *Juniperus monosperma*, *J. deppeana*, *J. scopulorum*, and *J. osteosperma*. Equations were constructed from visually estimated volumes, and diameter and height measurements sampled from 230 plots throughout the State. The volume definition included wood and bark of all aboveground bole, stem, and branch material with diameter 3.8 cm (1.5 inches) and larger. Results were compared to other pinyon-juniper equations from neighboring States.

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INTRODUCTION

Pinyon and juniper species occur in dryland forests throughout the Southwestern United States. More than half of New Mexico's forested landscape is dominated by pinyon-juniper (fig. 1). This area totals about 3.5 million hectares, or 11 percent of the State's land area (Fowler and others 1985; Van Hooser and others 1993). In addition, pinyon-juniper species are mixed with other forest types (primarily ponderosa pine) on another 1 million hectares (New Mexico FIA Data). Among New Mexico's pinyon-juniper species, pinyon (*Pinus edulis* Engelm.) predominates, accounting for 58 percent of the trees. The rest is divided among four juniper species—25 percent oneseed juniper (*Juniperus monosperma* [Engelm.] Sarg.), 7 percent alligator juniper (*J. deppeana* Steud.), 7 percent Rocky Mountain juniper (*J. scopulorum* Sarg.), and 3 percent Utah juniper (*J. osteosperma* [Torr.] Little).

Wood volume or biomass information is often needed for pinyon-juniper management or study, just as similar information is needed for other forest types. Some pinyon-juniper volume prediction equations are available for States neighboring New Mexico (Chojnacky 1985, 1988) or for small areas within the State (Clendenen 1979; Fowler and others 1984), but none have been developed or tested for the entire State. Recent inventories provided an opportunity to collect volume data to construct statewide volume equations for pinyon and juniper species. These inventories were coordinated or conducted by the U.S. Department of Agriculture, Forest Service, Interior West Resource Inventory, Monitoring, and Evaluation Program through its Forest Inventory and Analysis activity (commonly called FIA). This paper presents some new pinyon-juniper volume equations for New Mexico.

The objectives of this paper are to:

- Present the methods used to obtain and prepare the pinyon-juniper data for volume modeling.
- Explain the modeling techniques used to construct the volume equations.
- Discuss the new equation results.

METHODS

Data were collected in cooperation with New Mexico's most recent forest inventory (Van Hooser and others 1993). Procedures for field measurements followed FIA guidelines (USDA 1986).

A

B

Figure 1—Pinyon site (A) near the eastern edge of the Santa Fe National Forest and a harsh juniper site (B) overlooking Cañon Largo in northwestern New Mexico.

Volume Data

Volume data were subsampled from inventory plots permanently established in a 5-km (3.1-mi) grid across the State (a few ownerships have slightly smaller or larger grids). Only plots identified as pinyon-juniper forest types (by FIA definitions) were included in the subsample. Pinyon-juniper found in ponderosa pine or other forest types was not sampled.

The subsample was selected as partly systematic, partly random, and partly subjective. An effort was made to represent the statewide inventory population, but it was not possible to use a single design for all ownerships because of the need to accommodate numerous cooperators. However, the species composition for the subsample—59 percent pinyon, 28 percent oneseed juniper, 6 percent alligator juniper, 5 percent Rocky Mountain juniper, and 2 percent Utah juniper—corresponded closely to the composition of the statewide inventory. Only the subsamples of alligator juniper and Rocky Mountain juniper appeared weak; the statewide inventory showed up to 20 percent of these species were in ponderosa and mixed-conifer forest types, which were not subsampled.

Volume measurement of sample trees was done by three different groups. FIA inventory crews measured 29 percent of the trees (trees came from 150 plots). Two National Forests (NFS), the Gila and Cibola, measured 12 percent of the trees (trees came from 47 plots). And the remaining 59 percent were measured by a study crew revisiting 47 FIA and 29 NFS plots. About 2 to 3 trees were sampled per FIA plot, about 3 to 5 trees per NFS plot, and about 9 to 13 trees per study plot. Altogether, 230 different plots were visited for data collection (fig. 2). A total of 575 juniper and 835 pinyon were measured, representing lands from all major owner groups—National Forests, Indian reservations, Bureau of Land Management (BLM), private, and other public. The tables in the appendix provide a more detailed breakdown of the sampling by ownership.

Most field plots were 0.04-ha (0.1-acre) circles, but forested areas with less than 30 percent crown cover were sampled with 0.08-ha (0.2-acre) plots. Trees on each plot were selected randomly by species within diameter classes. This purposely sampled all tree sizes of each species found on a plot. Tree measurements included total height (*H*), diameter at groundline near the root collar (*DRC*), and the number of stems at the root collar. For trees forking at the root collar, equivalent diameter (*EDRC*) was calculated in place of *DRC* (Batcheler 1985):

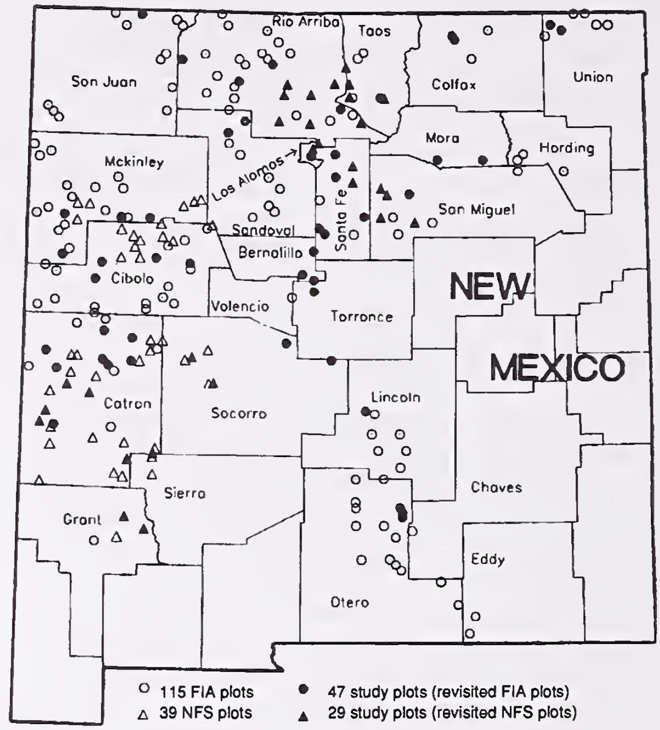

Figure 2—Forest Inventory and Analysis (FIA), National Forest System (NFS), and study crews measured 575 juniper and 835 pinyon on 230 plots.

$$EDRC = \sqrt{\sum_{i=1}^{n} d_i^2} \qquad (1)$$

where

n = number of stems at root collar with diameter 3.8 cm (1.5 inches) or larger

d_i = stem diameter.

Wood volume for each pinyon or juniper sample tree was estimated with a nondestructive technique commonly called "visual segmentation" (Born and Chojnacky 1985). This was done by dividing a tree's stems and branches into segments for systematic counting. Segments were grouped into 5-cm (2-inch) diameter classes having 0.3- to 1.8-m (1- to 6-ft) long sections. Some segment dimensions in lower portions of trees were measured, but most were estimated by sight.

Volume Calculations

Volume was computed for each segment using Huber's log formula (Husch and others 1982, p. 101) as modified for visual segmentation data (Chojnacky and Born 1992):

$$S_j = \eta \cdot \bar{d}^2 \cdot l_{mr} \quad (2)$$

where

S_j = segment volume (dm^3 or ft^3)

η = 0.154445 for dm^3 volume, 0.005454 for ft^3 volume

$$\bar{d} = l + \frac{1}{\lambda} + w\left[\frac{1}{(1-e^{\lambda w})}\right]$$

l = lower endpoint of segment diameter class (inches)

λ = 0.6523 for juniper, 0.7027 for pinyon

w = diameter class interval width (inches)

l_{mr} = midrange of segment length class (ft).

The volume of each tree was obtained by summing its individual segments ($\Sigma_{j=1}^{m} S_j$, m = number of segments per tree). This yielded an individual tree volume that included all aboveground fiber of stems and branches with outside-bark diameters larger than 3.8 cm (1.5 inches). Also, volume for a 7.6-cm (3-inch) minimum branch diameter was calculated by ignoring the smallest segment class. This volume corresponded to merchantable fuelwood standards common among many users. Both live and dead wood were included in volume calculations.

VOLUME MODELING

As for most tree species, pinyon-juniper volume is highly correlated with the tree diameter and height (Chojnacky 1988). This correlation was modeled by relating volume to the combination variable, *DRC* squared times height (D^2H), in an appropriate form. Data were checked and grouped before model parameters were estimated.

Model Form

Exploratory graphing of D^2H against volume showed patterns similar to past studies. Therefore, a model form previously used for Arizona data was selected (Chojnacky 1988):

$$V = \begin{cases} \beta_0 + \beta_1 X + \beta_2 X^2 & \text{for } X \le X_0 \\ \beta_3 + \beta_1 X + \beta_4 / X & \text{for } X > X_0 \end{cases} \quad (3)$$

where

V = gross voume of wood and bark of all stems and branches

X = $D^2H/2{,}000$

X_0 = inflection-point parameter estimated from data

β's = equation parameters estimated from data.

The first part of equation (3) (for $X \le X_0$) models most of the trees with a parabola, while the second part accounts for the decreasing trend in volume-to-D^2H for larger trees. Other more complex nonlinear model forms were considered, but exploratory data fitting showed no model better than equation (3).

Equation (3) was simplified by imposing two restrictions to make the model smooth and continuous at X_0:

$$\beta_3 = \beta_0 + 3\beta_2 X_0^2 \quad (4)$$

$$\beta_4 = -2\beta_2 X_0^3 \quad (5)$$

Resulting substitution reduced the number of parameter estimates needed from six to four:

$$V = \beta_0 + \beta_1 X + \beta_2 X' \quad (6)$$

where

$$X' = \begin{cases} X^2 & \text{for } X \le X_0 \\ 3X_0^2 - 2X_0^3/X & \text{for } X > X_0. \end{cases}$$

Data Checking and Grouping

Before estimating equation (6) parameters, several data items were examined: (1) FIA, NFS, and study data sources, (2) single- and multiple-stem trees, and (3) species groupings.

Data Sources—Forest Inventory and Analysis, NFS, and study data were compared for possible differences because of a recent finding on segmentation bias (Chojnacky and Born 1992). That study showed visual segmentation procedures allowed field crews too much flexibility in classifying segment lengths, a potential source of estimation error.

No quality control trees were common to all data sources. However, the study data were subsampled from FIA and NFS plots, providing some opportunity for comparison. Because all study data were estimated by a single person, study data were compared to FIA and NFS data to look for possible differences in techniques used by the different crews.

A comparison was devised by overlaying quadratic regression curves (equation [3] for $X \le X_0$) for FIA, NFS, and study data onto confidence intervals computed from the study data's regression. As a precaution against being misled by a few highly variable large trees, only trees with D^2H less than 10,000 were tested. For FIA data, volume predictions were less than predictions from study data on trees of similar size. Also these differences were mostly outside of 95 percent confidence intervals constructed around mean predicted values for study data (fig. 3). The NFS predictions were mostly within the study data's confidence intervals.

The difference between study and FIA data suggests possible inconsistency in field procedure, but it was not possible to determine which data source, if either, was biased. Analysis after this study showed the study crew *overestimated* segmentation volume (Chojnacky and Born 1992). A previous field check

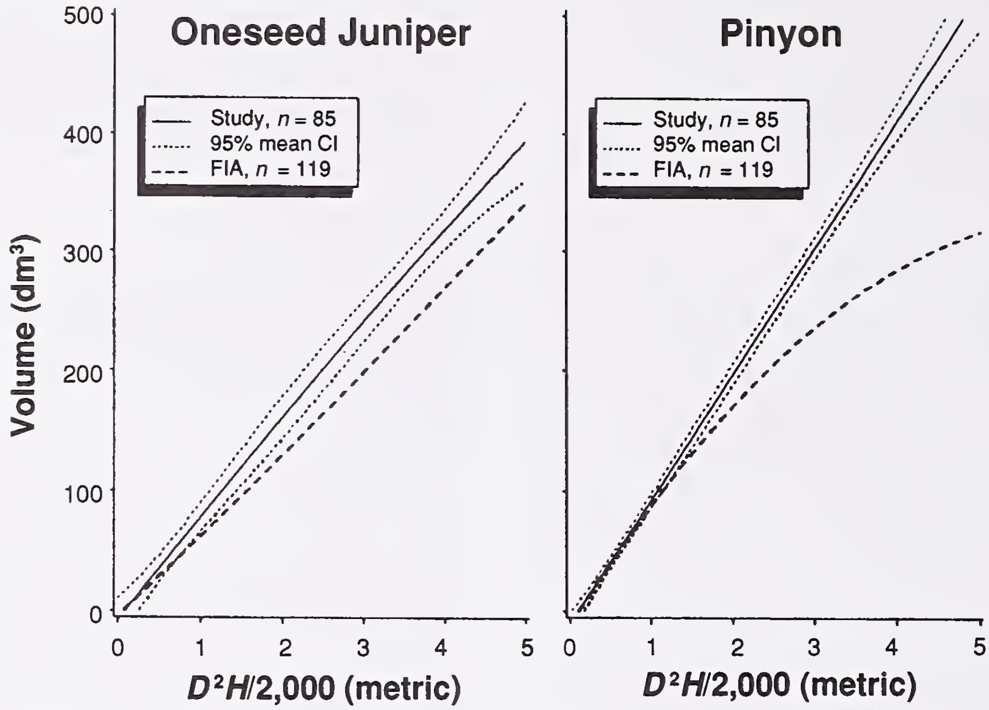

Figure 3—Regression comparison of Forest Inventory and Analysis (FIA) and study data for northwestern New Mexico counties where the two data sources overlap. A 95 percent confidence interval (CI) for mean predictions is shown for the study data. Regression R^2 values ranged from 0.83 to 0.94.

in Nevada showed BLM and FIA crews tended to *underestimate* volume (Born and Chojnacky 1985). All data sources were grouped in hopes some biases would cancel others out.

Single Versus Multiple Stem—Support for separate single- and multiple-stem volume equations was evident from graphs of volume data, but additional analysis raised some questions. Quadratic regression curves (equation [3] for $X \leq X_0$) overlaid on all available data showed multiple-stem trees have less volume than do single-stem trees of the same DRC^2H dimensions. But the differences were less when the test data were restricted to plots having both single- and multiple-stem trees. Therefore, it seemed best to combine single- and multiple-stem trees to avoid the possibility of being misled by unexplained correlation in initial data graphs. Perhaps volume variation among pinyon-juniper trees of the same dimensions is more closely related to site attributes than to stem branching.

Species Groups—Graphs of the New Mexico volume data showed large differences between pinyon and all juniper species that readily justified a separate pinyon model. However, it was more difficult to determine differences between individual juniper species due to problems of confounding sample sizes and taxonomy.

Utah and oneseed juniper were combined and called oneseed juniper. The sample included only 27 Utah juniper; there was concern—from revisiting study plots—that some oneseed juniper had been called Utah juniper. The two species hybridize and are very difficult to distinguish when growing together.

Oneseed juniper, alligator juniper, and Rocky Mountain juniper showed some differences in volume-to-D^2H graphs. Oneseed juniper, which included over 70 percent of the juniper sample, was kept separate. But alligator juniper and Rocky Mountain juniper were grouped because there were too few trees to reasonably construct separate equations for each species. Also, the sample did not include alligator juniper and Rocky Mountain juniper data from ponderosa pine forests—their better growing sites—making it even more reasonable to put them into a interim "catch-all" category.

The three final species groups included 835 pinyon, 416 oneseed juniper (389 oneseed juniper and 27 Utah juniper), and 159 alligator/Rocky Mountain juniper (90 alligator juniper and 69 Rocky Mountain juniper).

Parameter Estimation

Once data were grouped, estimating parameters for the volume equation was straightforward. Nonlinear regression (Gauss-Newton Taylor series computation method; SAS 1989, p. 1153) was used to estimate β_0, β_1, β_2, and X_0 in equation (6). A regression weight of $D^2H^{-1.5}$ was used to stabilize volume variation among different tree sizes and to improve volume prediction for small trees.

Some type of weighting is needed when estimating parameters in volume equations (Cunia 1964). Schreuder and Anderson (1984) suggested volume equations use a weight function of $D^2H^{-\lambda}$, where λ = 1.5. This choice of λ was compared to a Park-Glejser method (Pindyck and Rubinfeld 1981, p. 151) where λ was estimated to be less than 1 for each species group. However, finding an optimum value for λ did not seem critical, because individual tree predictions from the two weighting methods differed by 1 percent or less.

RESULTS

Equation (6) parameters were estimated for volume to 3.8- and 7.6-cm (1.5- and 3.0-inch) minimum branch diameters (table 1). Two regression-fit statistics—the coefficient of determination (R^2) and the coefficient of variation (*C.V.*)—were computed from regression residuals without considering regression weights. Values for R^2 were 0.88 or higher.

Graphs of regression residuals were examined to see how well the model fit the data. Even distributions of residuals above and below the residual graph's center line (residual = 0) justified the model choice for all regressions (fig. 4). The residual graphs were examined in original volume units, instead of weighted units.

Table 1—Volume equation parameters estimated from New Mexico data

Species[1]	Measurement units	Minimum branch diameter	Parameter estimates[2] β_0	β_1	β_2	X_0	Number of trees	Fit statistics R^2	*C.V.*
		cm or inches							*Percent*
Jude/Jusc	metric	3.8	0.7230	50.3390	5.8395	3.9352	159	0.94	38
Jude/Jusc	metric	7.6	–1.7013	39.8752	4.5857	5.1226	159	.95	38
Jumo/Juos	metric	3.8	–.5447	61.3367	3.2233	2.5325	416	.90	38
Jumo/Juos	metric	7.6	–3.0094	41.3948	3.8768	3.9568	416	.88	46
Pied	metric	3.8	–1.6831	75.9117	9.5142	2.0425	835	.91	49
Pied	metric	7.6	–3.4868	59.7330	5.3635	3.4908	835	.92	50
Jude/Jusc	English	1.5	.0255	1.7479	.1994	4.0021	159	.94	38
Jude/Jusc	English	3.0	–.0601	1.3846	.1566	5.2101	159	.95	38
Jumo/Juos	English	1.5	–.0192	2.1297	.1100	2.5757	416	.90	38
Jumo/Juos	English	3.0	–.1063	1.4373	.1324	4.0243	416	.88	46
Pied	English	1.5	–.0594	2.6358	.3248	2.0773	835	.91	49
Pied	English	3.0	–.1231	2.0741	.1831	3.5503	835	.92	50

[1]*Juniperus deppeana* (Jude), *J. monosperma* (Jumo), *J. osteosperma* (Juos), *J. scopulorum* (Jusc), *Pinus edulis* (Pied).
[2]Volume equation:

$$V = \begin{cases} \beta_0 + \beta_1 X + \beta_2 X^2 & \text{for } X \le X_0 \\ \beta_0 + \beta_1 X + \beta_2 (3X_0^2 - 2X_0^3/X) & \text{for } X > X_0 \end{cases}$$

where

V = gross outside-bark volume of stem and branch wood (dm³ or ft³)
X = DRC^2H/2,000 for metric units or DRC^2H/1,000 for English units
DRC = tree diameter near groundline at root collar (cm or inches)
H = perpendicular distance from groundline to top of tree's tallest stem (m or ft).

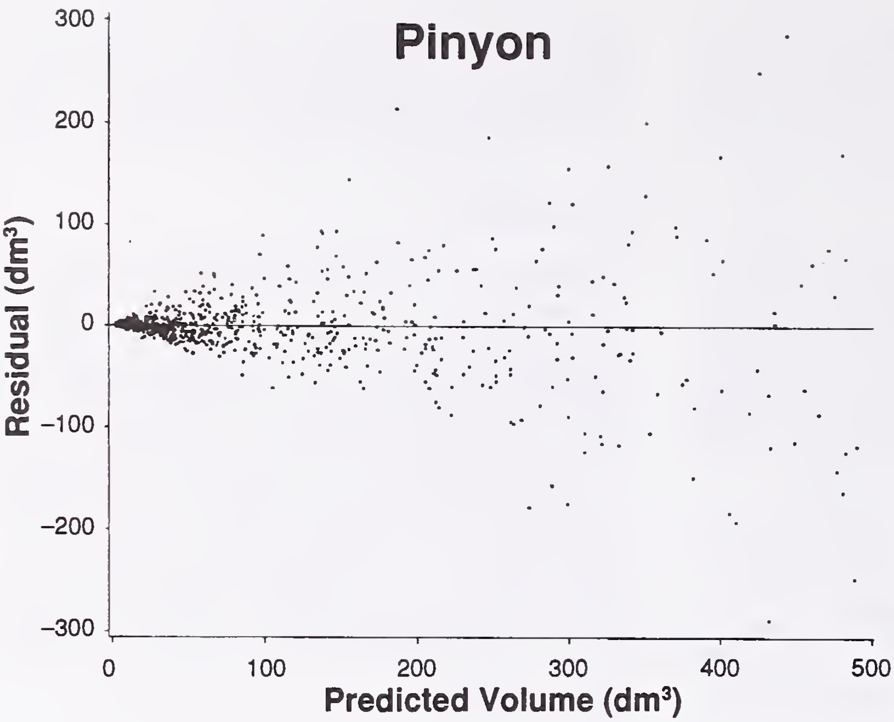

Figure 4—Residuals (measured volumes minus regression predictions) compared to predictions. Residuals are in volume units instead of weighted regression units. Residuals are evenly distributed above and below the center line (residual = 0).

Comparison of the final equations showed pinyon volume predictions were higher than juniper predictions for same size trees (fig. 5). But differences between the two juniper equations appeared minimal, except for larger trees.

The new volume equations were compared to other pinyon-juniper equations developed for similar lands outside New Mexico (Chojnacky 1985, 1988). The New Mexico equations mostly predicted volumes 10 to 30 percent larger than those from neighboring States (fig. 6).

CONCLUSIONS

Pinyon-juniper volume equations were constructed for the entire State of New Mexico (table 1). Volume included wood and bark of all branches 3.8 cm (1.5 inches) and larger. Using the equations requires that tree diameter and height be measured.

Equation parameters were estimated for one pinyon species and two juniper species groups. The two juniper equations were based more on data availability than on objective comparison among juniper species. If more alligator and Rocky Mountain juniper data had been available—and the additional data were similar to available data—only one juniper equation would have been developed.

Comparison of the volume equations to those from neighboring States showed noticeable differences among volume predictions (fig. 6). These differences could reflect problems with methodology as well as

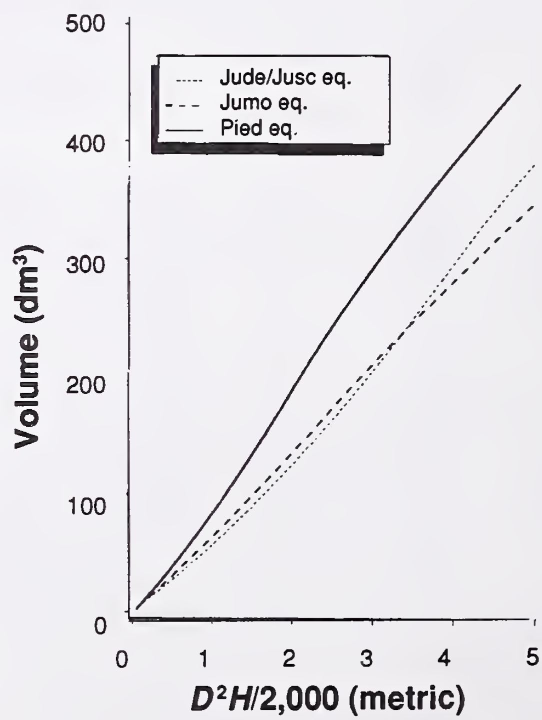

Figure 5—Comparison of final volume equations (eq.) among *Pinus edulis* (Pied), *Juniperus monosperma* (Jumo), and *J. deppeana*/*J. scopulorum* (Jude/Jusc). Volume is predicted for all wood with branch diameters 3.8 cm (1.5 inches) and larger.

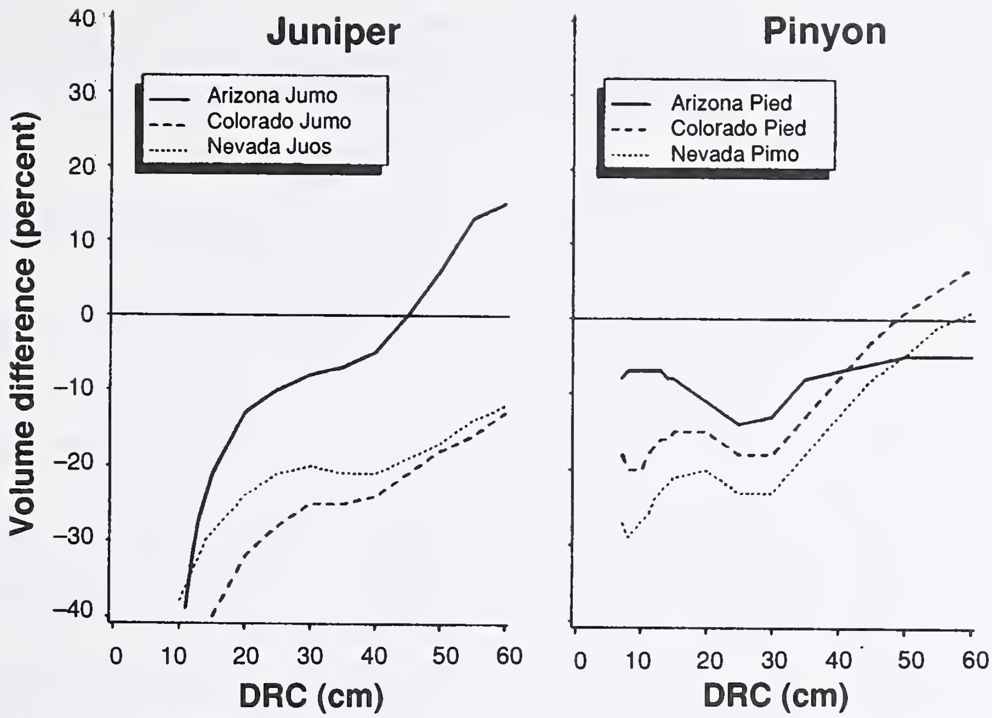

Figure 6—New Mexico's *Juniperus monosperma* (Jumo) and *Pinus edulis* (Pied) volume equations compared to Arizona's and Colorado's equations, and compared to Nevada's *J. osteosperma* (Juos) and *P. monophylla* (Pimo) equations. Volume difference is the respective State's volume prediction minus the New Mexico prediction, divided by the New Mexico prediction. If the predicted volumes were the same for the equations being compared, the equations would correspond to the line at 0. The DRC is a tree's diameter at groundline near the root collar.

differences due to geography. Unfortunately, choosing an appropriate equation is not a simple matter of matching a State with its published equations. The selection is complicated by evolving field procedures, a recent discovery of a bias in the segmentation technique, and gaps in volume data collected for particular States.

One way to judge between volume equations is to graph or tabulate all equations for the same *DRC* and *H* measurements. For example, this approach showed New Mexico equations predicting 10 to 25 percent more volume than Arizona and Colorado equations for trees 30 cm *DRC* (fig. 6). From previous discussion about data sources and segmentation methodology, it is unlikely that these differences are due just to geography. Therefore, users seeking to compare volumes in two States probably should choose a single equation for both States or use each State's equations on each tree and average the results.

Another way to avoid problems in comparative analyses would be to use actual inventoried tree measurements. Because D^2H is proportional to volume and can be measured accurately, it could be used to compare the amount of wood among pinyon-juniper stands or between States. For example, D^2H could be averaged into diameter classes for comparative analysis. Volume equations could then serve as a "last step" conversion factor relating D^2H to more meaningful volume units.

Finally, visual segmentation data could be collected on a small sample of test trees for the local area of interest. The volume equation that best predicts the test data could then be used.

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APPENDIX

This appendix contains a summary of the raw data sampled throughout New Mexico (tables 2 and 3). Data are grouped by ownership or by agency managing the land.

Table 2—Juniper volume segmentation data sampled in New Mexico, 1985 to 1988

Ownership or management agency	Mean volume	Mean *DRC*	*DRC*²*H*/2,000 distr. percentiles[1] 5th	50th	Max.	No. of trees	Data source FIA	NFS	Study	Single-stem trees	Species[2] Jumo	Jude	Jusc	Juos
	dm³	*cm*	- - - - - *Metric* - - - - -				- - - - - - - - - - *Percent* - - - - - - - - - -							
Corporate	119	26	0.1	1.2	11.9	27	67	0	33	44	59	26	15	0
Private individual	148	28	.2	1.1	14.1	124	47	0	53	35	83	1	15	1
Total private	143	28	.1	1.2	14.1	151	50	0	50	36	79	5	15	1
Carson National Forest	54	18	.1	.4	3.7	24	0	0	100	58	67	0	33	0
Cibola National Forest	192	31	.2	1.4	26.5	52	0	81	19	31	67	15	13	4
Gila National Forest	152	25	.2	.9	11.7	72	0	61	39	51	22	68	1	8
Lincoln National Forest	213	31	.2	1.8	16.2	26	100	0	0	46	81	19	0	0
Santa Fe National Forest	61	19	.1	.5	4.6	29	0	0	100	45	66	0	34	0
Total National Forest	146	26	.2	.9	26.5	203	13	42	45	45	53	31	13	4
Jicarilla Reservation	200	35	.5	2.5	18.6	17	100	0	0	41	59	0	41	0
Laguna Reservation	160	32	.3	2.2	4.0	12	42	0	58	0	100	0	0	0
Mescalero Reservation	115	20	.1	.5	11.6	19	5	0	95	68	5	95	0	0
Navajo Reservation	267	38	.4	2.8	32.8	33	76	0	24	27	85	0	15	0
So. Pueblos Reservations	150	32	.2	1.1	9.1	24	58	0	42	8	100	0	0	0
Zuni Reservation	72	25	.1	.9	3.9	9	67	0	33	0	100	0	0	0
Total Reservation	180	32	.1	1.3	32.8	114	60	0	40	27	74	16	11	0
Albuquerque BLM[3] District	229	37	.4	3.2	12.4	48	71	0	29	29	60	2	2	35
Las Cruces BLM District	230	38	.7	2.2	18.1	25	24	0	76	12	96	4	0	0
Total BLM	229	38	.4	2.2	18.1	73	55	0	45	23	73	3	1	23
Other public	36	17	.1	.4	1.7	7	29	0	71	14	100	0	0	0
State	204	33	.2	2.9	10.6	27	41	0	59	37	70	0	26	4
Total misc. public	169	30	.1	1.7	10.6	34	38	0	62	32	76	0	21	3
Total all ownerships	164	29	.1	1.3	32.8	575	39	15	46	36	68	16	12	5

[1]These percentiles indicate relative tree sizes in sample distributions for respective ownerships.
[2]*Juniperus deppeana* (Jude), *J. monosperma* (Jumo), *J. osteosperma* (Juos), *J. scopulorum* (Jusc).
[3]Bureau of Land Management.

Table 3—Pinyon[1] volume segmentation data sampled in New Mexico, 1985 to 1988

Ownership or management agency	Mean volume	Mean *DRC*	*DRC²H/2,000* distr. percentiles[2] 5th	50th	Max.	No. of trees	Data source FIA	NFS	Study	Single-stem trees
	dm³	*cm*	- - - - - - *Metric* - - - - - -				- - - - - - - - - - - *Percent* - - - - - - - - - - -			
Corporate	118	19	0.1	0.7	23.6	63	24	0	76	89
Private individual	168	21	.1	.8	14.4	179	26	0	74	89
Total private	155	21	.1	.8	23.6	242	25	0	75	89
Carson National Forest	145	19	.1	.9	20.9	99	0	0	100	94
Cibola National Forest	192	23	.2	1.1	19.8	61	0	72	28	84
Gila National Forest	152	20	.2	.9	10.4	121	0	33	67	97
Lincoln National Forest	101	18	.1	.6	6.5	50	100	0	0	98
Santa Fe National Forest	99	17	.1	.6	9.9	89	0	0	100	92
Total National Forest	139	19	.1	.8	20.9	420	12	20	68	93
Jicarilla Reservation	168	26	.3	1.8	5.8	7	100	0	0	100
Mescalero Reservation	69	16	.1	.5	3.7	16	13	0	88	94
Navajo Reservation	282	25	.1	1.1	24.4	43	60	0	40	91
So. Pueblos Reservations	160	21	.1	.6	7.3	13	31	0	69	85
Zuni Reservation	110	16	.1	.2	8.2	7	43	0	57	100
Total Reservation	201	22	.1	.7	24.4	86	49	0	51	92
Albuquerque BLM[3] District	90	19	.1	.6	5.2	35	46	0	54	83
Las Cruces BLM District	50	17	.2	.5	1.6	8	25	0	75	100
Total BLM	83	18	.1	.5	5.2	43	42	0	58	86
Other public	385	28	.2	2.6	10.6	9	0	0	100	100
State	96	17	.1	.4	4.5	35	26	0	74	94
Total misc. public	155	19	.1	.5	10.6	44	20	0	80	95
Total all ownerships	148	20	.1	.8	24.4	835	22	10	68	92

[1]*Pinus edulis.*
[2]These percentiles indicate relative tree sizes in sample distributions for respective ownerships.
[3]Bureau of Land Management.

Chojnacky, David C. 1994. Volume equations for New Mexico's pinyon-juniper dryland forests. Res. Pap. INT-471. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station. 10 p.

Volume equations were developed to predict cubic volume for New Mexico's pinyon-juniper species. The volume equations estimate wood and bark of all aboveground bole, stem, and branch material with diameter 3.8 cm (1.5 inches) and larger. Use of the equations require diameter and height measurements.

KEYWORDS: woodland, *Pinus edulis*, *Juniperus monosperma*, *J. deppeana*, *J. scopulorum*, *J. osteosperma*, diameter at root collar

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